# THE NASA SPACE NETWORK DEMAND ACCESS SYSTEM (DAS)

## Thomas A. Gitlin

NASA Goddard Space Flight Center, Greenbelt, MD 20771

## Walter Kearns & William D. Horne

ITT Industries, Advanced Engineering and Sciences, 1761 Business Center Drive, Reston VA 20190

## Abstract

The Demand Access System (DAS) of the NASA Space Network offers a new and innovative service for space operations by providing continuous and automated communication links via the Tracking and Data Relay Satellite System (TDRSS). Operational in October 2002, the Demand Access System expands the TDRSS Multiple Access return (spacecraft-to-ground) capabilities by building on the availability of ground-based Commercial Off-the-Shelf (COTS) systems, such as the Third Generation Multiple Access Beamformer Subsystem (TGBFS) and the Programmable Telemetry Processor (PTP), and by using networking standards, including TCP/IP and web-based interfaces. This paper reviews the DAS architecture, noting the use of COTS hardware components, as well as its automated approach to space operations for Earth-science and space science missions.

## 1 Introduction

Starting in the late 1970s, NASA's Goddard Space Flight Center (GSFC) developed the Space Network, including TDRSS, to provide global connectivity between mission control centers and their low earth orbiting (LEO) spacecraft [1]. Before the development of DAS, TDRSS, which has long been used to provide reliable low- and high-data rate relay services, implemented services based on prior user scheduling of the available communications links. Non-DAS service scheduling is completed days in advance of the actual event and is based upon estimates of user needs and mission event timelines. While this approach has in the past been adequate for providing service to a few larger spacecraft with well-defined operations, the desire to provide responsive, automated services to smaller missions and at reduced cost lead to the design and development of an "on-demand" service.

Although the concept and design has evolved over time [2, 3, 4], DAS exploits the Tracking and Data Relay Satellite (TDRS) on-board phased array antenna system and existing networking technologies. Using COTS beamforming systems and an optical-based distribution system, DAS greatly expands the number of users that can be supported simultaneously including the use of dedicated equipment chains that can track a spacecraft continuously throughout its orbit. Services are coordinated through the Space Network Web Services Interface (SWSI). DAS's use of existing processing systems (e.g., Programmable Telemetry Processors (PTP)) and networking standards and web-based interfaces provides the mission operator with an automated communications operation.

As NASA and other space agencies operate a greater number of smaller spacecraft including missions with spacecraft in formation, these missions require affordable and flexible communication capabilities. The Space Network's DAS is strategically positioned to be an efficient service provider to this class of customers and to emerging space internetworking concepts [5, 6, 7]. The modular DAS architecture provides a low-data rate, low-cost service that can be easily expanded to a nearly limitless number of users. Emerging missions desire dedicated, continuous (24x7) links for receiving telemetry data to enable rapid re-pointing of instruments for observation of cosmic and earth-based events. DAS enables this type of innovative mission operation. DAS can also serve emerging space-based investigations using multiple spacecraft flying in formation through its efficient approach to processing multiple-emitter communications in a single or multiple antenna beams.

## 2    DAS Functions and Services

TDRSS is a communication signal relay system which provides tracking and data acquisition services between low earth orbiting spacecraft and customer Mission Operations Centers (MOCs), as shown in Figure 1.  The Space Network is capable of transmitting to (forward) and receiving data from (return) customer spacecraft over 100% of their orbit.  Three TDRS spacecraft can provide continual global service coverage.  Those designated for DAS services are the outer East (Atlantic Ocean) and West (Pacific Ocean) TDRS's within a cluster, and the backside TDRS at 275W that covers the area over the Indian Ocean.  The East and West TDRS spacecraft are connected to the terrestrial NASA networks via the White Sands Complex, consisting of two ground stations, the White Sands Ground Terminal (WSGT) and the Second TDRSS Ground Terminal (STGT), while the backside TDRS communicates with the Guam Remote Ground Terminal (GRGT).  GRGT connects to the WSC via a terrestrial network.

DAS expands the current Space Network Multiple Access (MA) return service (spacecraft-to-ground) by providing:

- Immediate access to services by the customer;
- Extended duration services;
- Simplified resource allocation and operation;
- Reduction of service cost; and,
- New capabilities such as immediate science alerts and autonomous requests for return service.

For traditional TDRSS operations, the return service requires significant coordination and pre-scheduling.  Signals transmitted by spacecraft are received by the TDRS MA on-board phased array antenna system.  The individual antenna element signals are relayed to the ground terminals where the antenna beams are formed by the Third Generation Multiple Access Beamformer Subsystem (TGBFS) and the signals are demodulated and transmitted to the spacecraft's MOC.  The ground-based TGBFS processes customer ephemeris to dynamically form beams on the customer spacecraft.  DAS alleviates the coordination burden and significantly increases the number of simultaneous links that can be supported.
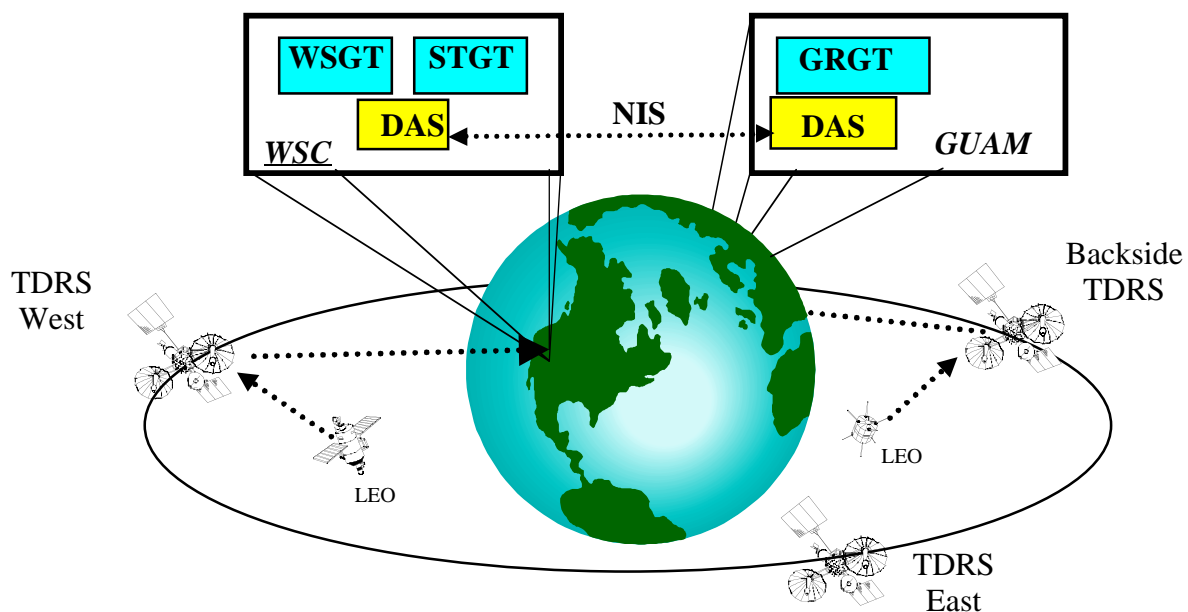


**Figure 1:  NASA Space Network and DAS**

DAS allows a customer to request a return link service connecting the customers' spacecraft through TDRSS at anytime and for extended durations. DAS customer resource allocation requests result in the automatic management of beamforming, demodulation, and return data distribution capabilities. The key functions for DAS are to:

- Provide a capability to support continuous or intermittent, conflict-free, DAS MA return link (spacecraft-to-ground) services globally anywhere in low earth orbit, 24 hours per day, 7 days per week, upon demand from customers;
- Provide an automated capability to transition DAS customer service communications between TDRSs and ground stations;
- Provide a capability to support multiple, DAS MA return links per TDRS and ground stations at data rates from 1 kbps up to 150 kbps per channel;
- Meet communications performance and capabilities of the existing MA return link with the exceptions of the functions not possible due to the lack of tie-ins with the MA forward (ground-to-spacecraft) link (such as coherent turnaround support, cross support, or two-way ranging);
- Provide beamforming, demodulation, data formatting, data distribution, and short-term storage capabilities of up to thirty days for each DAS service;
- Automate the operation and scheduling of all DAS return link resources;
- Provide resource allocation accounting;
- Provide simple, low cost, modular beamforming, demodulation, routing and storage functions, which can be modularly expanded to add DAS return link channels as needs change; and,
- Provide customers with the capability of obtaining DAS services on a dedicated or non-dedicated basis, subject to preemption by higher priority customers.

There are two classes of customers: dedicated and non-dedicated. A dedicated customer has a "guarantee" of service while a non-dedicated customer is not provided services on a guaranteed basis, but rather on an on-demand basis, assuming sufficient resources. If a dedicated customer needs resources, it can bump resources from both non-dedicated and lower-priority dedicated users. Because of the modular design, DAS must ensure sufficient equipment chains are available to meet the expected number and mix of dedicated and non-dedicated customers.

DAS supports several customer scenarios:

- Continuous: this customer requires a 24x7 real-time link for continuous service or monitoring for alerts ("911" services). DAS provides continuous coverage except for short (< 15 second) periods when the customer spacecraft is switched between relay satellites.
- Intermittent/On demand: the customer will download data during a single requested event.
- Special Operations (e.g., Formation Flying): A group of emitters are closely spaced in the same orbit so several demodulators can receive the output of a single beamformer.

## 3  DAS Architecture

### 3.1  Development Approach

The DAS development and deployment approach established a basic operational infrastructure using a mix of COTS (both common and specialized) and custom-built elements. In addition, the development philosophy included employing networking standards and interfaces (i.e., TCP/IP, web browser) where possible to facilitate its integration into available networking resources. Essentially, the DAS development was a semi-custom COTS integration effort with extensive software development.

Taking advantage of previous efforts in developing specialized COTS items for use with TDRSS (e.g., TGBFS, PTP), the DAS development applied the following approach:

- Use COTS beamformers (TGBFS) to provide core beamforming capabilities;
- Modify existing TGBFS controllers to interface with DAS;
- Modify the software of a COTS programmable demodulator to handle DAS MA-return capabilities;
- Add COTS switching between the ground stations and beamformers, and between beamformers and demodulators;
- Add data formatting and COTS archiving capabilities (PTP);
- Develop custom demodulator and system controllers (software) running on COTS processors;
- Use an existing web-based system (SWSI) for customer request and status exchange; and,
- Use existing NASA IP-based networks (NISN IOnet) for customer return telemetry data transport.

## 3.2  Reference Architecture

Figure 2 illustrates the DAS reference architecture including key external interfaces.  The basic architecture consists of the control/monitoring, switching, and data storage capabilities to facilitate expansion of beamforming and data demodulation.  The infrastructure uses a single beamforming group (Independent Beamformer Unit Group (IBUG)) for each of the three TDRS regions ((1) East (Atlantic), (2) West (Pacific), and (3) "backside" (Indian)), and a demodulator at each ground site.  Two IBUGs and a Demodulator Group (DMG) reside at the WSGT and one of each device resides at the GRGT.  The full operational capability of DAS consists of ten IBUGs and eight DMGs at both WSGT and GRGT.

The external interfaces support customer service requests and status through SWSI, the transport of telemetry data to customers over the NISN IOnets, and the receipt of satellite signals from the Element Multiplexer Correlator (EMC) at the ground sites (WSC and GRGT).  In addition, the Local Control and Monitor (LCM) interface provides the DAS operators with a Graphical User Interface (GUI) for control and monitoring.

The key difference in the two ground sites is the presence of the DAS Controller (DASCON) and the fiber optic switch at WSGT.  DASCON provides system control for both WSGT and GRGT configurations.  The WSGT installation interfaces with four EMCs, which requires a fiber optic switch and Common Data Broadcast switch that are not needed to support the single EMC interface at GRGT.  Routers provide connectivity between WSGT and GRGT over the Guam Data Information System (GDIS) network.  For security, separate routers on the GDIS network handle customer service data and DAS status and control information.  All customer service data downlinked at GRGT travels to WSGT over GDIS and then through the smart data hub and over the NISN Closed IONet to customer destinations.

In both the GRGT and WSGT installations, signal/data flows through the hardware elements of the system starting from an EMC/EMC Switch to the fiber optic switch (at WSGT) to the IBUGs, through the IF switch, to the demodulators, to the data archive server (PTP), and then to the smart data hub and to the NISN closed IOnet.  Software subsystems, ICON, and DCON provide monitoring and control of their hardware components at both sites.  Up to fifty customer data streams will be supportable from each site in this fully operational configuration.

## 3.3  Interface Elements and the Use of Networking Standards

The DAS external interfaces exploit either specialized interfaces with the Space Network or use interfaces based on common networking standards.  These interface elements include:

- **Element Multiplexer Correlator (EMC) Interface Subsystem**:  An optical switch in the EMC Interface subsystem provides the interface between the White Sands Ground Terminal/Second TDRSS Ground Terminal (WSGT/STGT) EMCs and the Independent Beamformer Unit Group (IBUG) subsystem.  The EMC Interface subsystem includes the Optical Switch, a Common Data

Broadcast (CDB) Switch, and ancillary cable connections. A single EMC can communicate with up to ten IBUGs. The IBUG Controller (ICON) controls the Optical Switch and the Optical Switch controls the CDB. The Fiber Optic Switch and the CDB switch pass beamforming information from the WSC EMCs to the IBUGs, and the switches receive control and send status data to ICON as part of the control and status network within DAS.
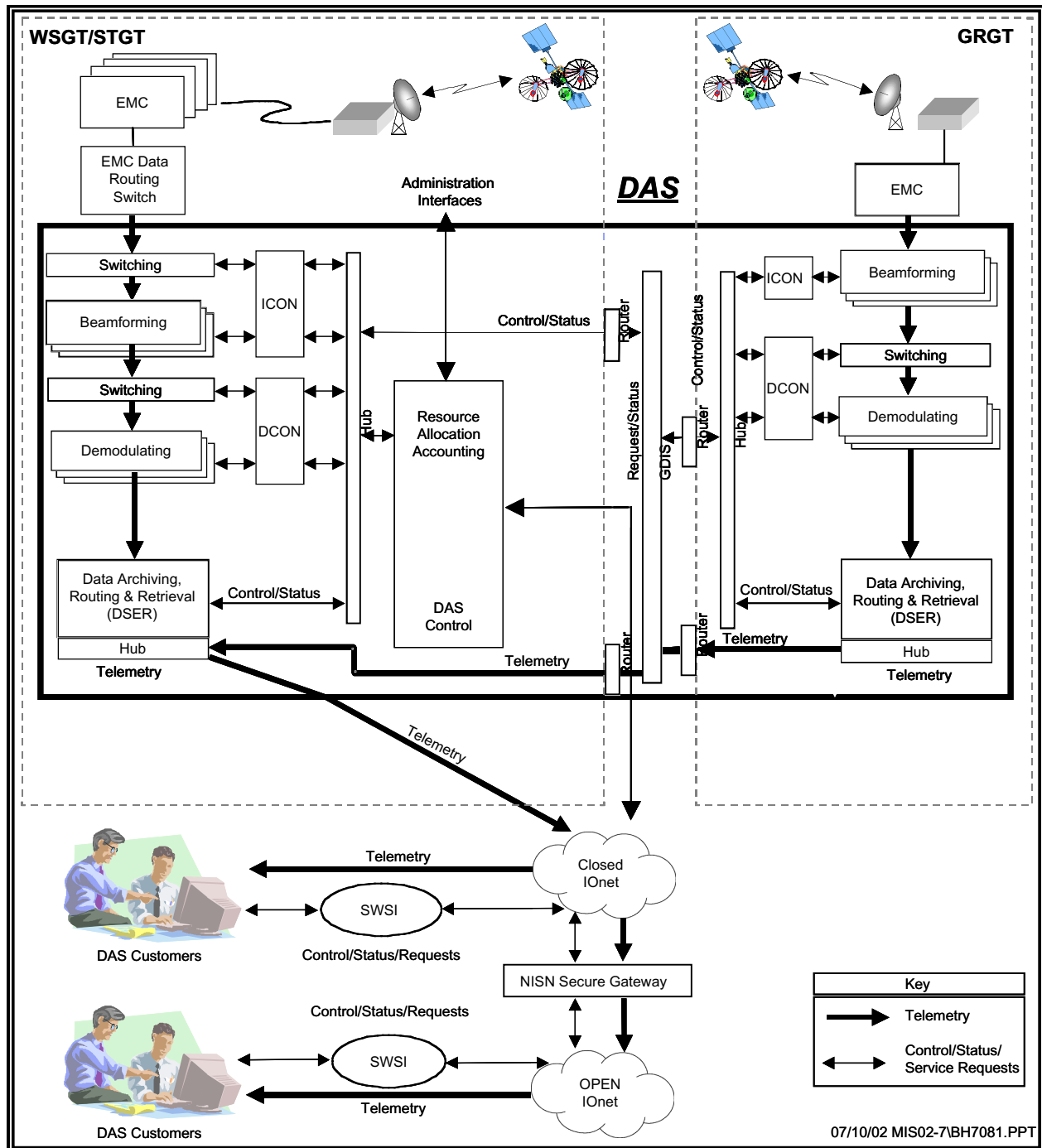


**Figure 2: Demand Access System (DAS) Reference Architecture**

- **Space Network Web Services Interface (SWSI)**: SWSI provides a standards-based customer interface for performing Tracking and Data Relay Satellite (TDRS) scheduling and real-time service monitoring and control, including DAS services. As a Java-based application accessed using a web browser, SWSI is cross-platform compatible, since there are web browsers and Java virtual machines available for almost every computer platform (Personal Computer (PC), Macintosh, Unix, etc.). Clients establish connections to the SWSI server using the Secure Socket Layer (SSL) protocol and authentication with digital certificates.
- **Integrated Service Network (NISN) Closed IP Operational Network (IONet) Interface:** COTS routers provide the networking (IP-based) connectivity between DAS and the IOnet. The PTPs in the Data Format/Archive Server establish TCP socket connections with the spacecraft MOCs and act as clients for distribution of the data in standard TCP/IP packets.

## 3.4 COTS: Common and Specialized

The primary hardware subsystems are COTS items, either standard or specialized ones for TDRSS. Several of the COTS items required modification, but the others were inserted without modification:

- **IBUG Subsystem**: An individual Beamforming Unit (IBU) in the IBUG subsystem accepts MA antenna element signals from the EMC and forms antenna beams to the satellite location, as commanded by the ICON. The resulting formed antenna beams are combined into a composite Intermediate Frequency (IF) signal (8.5 MHz) for subsequent demodulation. IBUGs send status data to ICON and receive control information from the ICON.
- **IBUG Controller (ICON) Subsystem**: This modified software COTS item controls the EMC Interface and IBUG and manages the interfaces between DASCON, EMC, and beamformers. The control software is hosted on a workstation terminal, which is an integral part of the Local Control Monitor (LCM). ICON accepts command from and sends status to DASCON.
- **IF Switch Subsystem**: The IF Switch provides the IF interfaces between Demodulator Units (DMUs) and IBUs. The IF switch is controlled by DCON.
- **Demodulator Group (DMG) Subsystem**: An individual Demodulator Unit (DMU) in the DMG subsystem receives IF signals from the IF Switch, demodulates the signals, and outputs baseband data to the Data Format/Archive Server via an Ethernet switch. The DMG receives command instructions from DCON and transmits status information to DCON once per second.
- **Data Format/Archive Server (DSER) Subsystem - Programmable Telemetry Processor (PTP)**: The DSER formats, archives, and routes baseband data over the NISN closed IOnet to DAS Customers. The DSER subsystem consists of PTPs, routers to interface with the GDIS network, and Ethernet hubs and switches to interface with the NISN closed IOnet and with local user interfaces. DASCON directly manages the status and control of the PTPs. The DAS PTP's can perform processing of specific Consultative Committee for Space Data Systems (CCSDS) data formats, and optionally encapsulate data into structured headers for transport, as well as provide data asynchronously (no header) in TCP/IP packets.
- **Power and Mechanical Subsystem**: This subsystem provides electrical power and the physical infrastructure. This subsystem is composed of standard COTS items.
- **Timing and Frequency Subsystem**: This subsystem provides system timing to the DSER, DCON, ICON, and DASCON and accurate frequency information to the DMG. Status information is reported to DASCON. This subsystem is composed of standard COTS items.

## 3.5 Custom Developed Elements

Two of the three controllers in DAS are custom developed software items:

- **DASCON Subsystem**: DASCON provides overall system status reporting and control with interfaces to ICON, DCON, the EMC Controller (ECON), the PTPs, and the NISN closed IOnet.

DASCON provides connectivity to DAS customers through the SWSI system for services planning, scheduling, and reporting. DASCON interfaces with the GDIS network to provide control and status for DAS hardware and software resources at GRGT. DASCON provides an interface for alerts to operators. The software is hosted on the DAS Local Control Monitor (LCM) workstation and consists of twelve independent software programs.

- **DCON Subsystem**: DCON controls the IF Switch, temperature monitor, and demodulators, and manages the interfaces between the IF Switch and demodulators. The control software is hosted on a workstation terminal. ICON accepts command from and sends status to DASCON.

## 4  Operations Process: "On-Demand" Automation

### 4.1  Overview

DAS provides customers with telemetry (return) services from customer spacecraft by planning and allocating resources to satisfy customer requests sent through SWSI via several activities:

- **Service Planning**: Through SWSI, DAS serves as a planning tool that provides customers with time windows available for DAS services

- **Service Request & Resource Allocation**:
  - o  DAS customers request services (e.g., continuous or one-time "on-demand) via SWSI
  - o  DAS "schedules" services and allocates resources for specific time periods

- **Service Activation**: DASCON automatically controls the overall service activation while ICON, DCON, and the DSER control specific equipment

- **Service Control**: During a scheduled service period, ICON, DCON, and the DSER capture status while DASCON provides the customer with status, alerts, and performance estimates via SWSI

- **Data Service**: DAS sends real-time telemetry or scientific data to customers over the NASA IP network (NISN Closed IONet) after the spacecraft signal has been captured via beamforming and the data has been demodulated, formatted, and TCP/IP encapsulated
  - o  The data can also be archived for playback later by the customer

### 4.2  Service Planning

Planning assists a DAS Customer in identifying periods of resource availability for future scheduling. As shown in Figure 3, DAS customers make requests for the availability of TDRS services through a SWSI terminal normally located in the customer MOC. SWSI then submits a Resource Availability Request message to DAS. For this request, DASCON computes time windows based on line-of-sight visibility calculations from the customer platform to a TDRS satellite. After determining periods of service availability, DASCON responds by providing the customer available visibility time windows (scheduling availability forecasts) for service through SWSI.

### 4.3  Service Scheduling and Resource Allocation

A DAS customer "schedules" real-time services or playback services (archived data) by submitting requests via SWSI. The customer submits a Resource Allocation Request message through SWSI to DAS consisting of the customer Spacecraft Identification Code (SIC), a request identifier, a Service Specification Code (SSC) identification number, and the SSC parameters needed to define the service (e.g., data rates, etc.). Also included in the message are the start and end times for the service being requested and the TDRS satellite identifier. SWSI allows DAS customers to store a predetermined number SSC profiles for requesting DAS services.
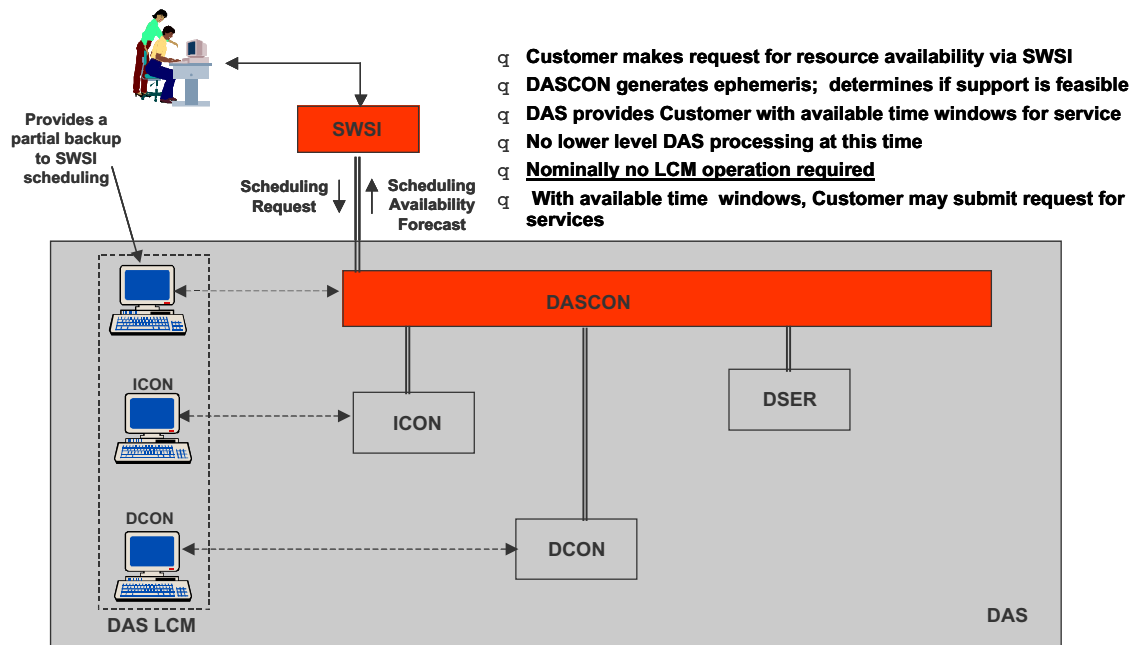
**Figure 3:  DAS Service Planning**

Upon receipt of the Resource Allocation Request, DASCON assesses availability of the DAS resources (beamformers, demodulators, and PTPs) needed to support the service during the requested times. DASCON propagates the customer spacecraft state vectors and assesses visibility.  Once a service is determined to be available and is scheduled, DASCON notifies customers via SWSI using a Resource Allocation Response Message.  DAS supports both dedicated (guarantee of service) and non-dedicated customers.  Non-dedicated customer requests are assigned within the resources remaining after allocation to dedicated customers.  Service requests may be for "continuous" service that continues indefinitely until the customer requests an end or for "on-demand" single-event services that have a definite start and stop time.  When a customer service is approved, it is placed on the DAS 96-hour sliding window schedule.
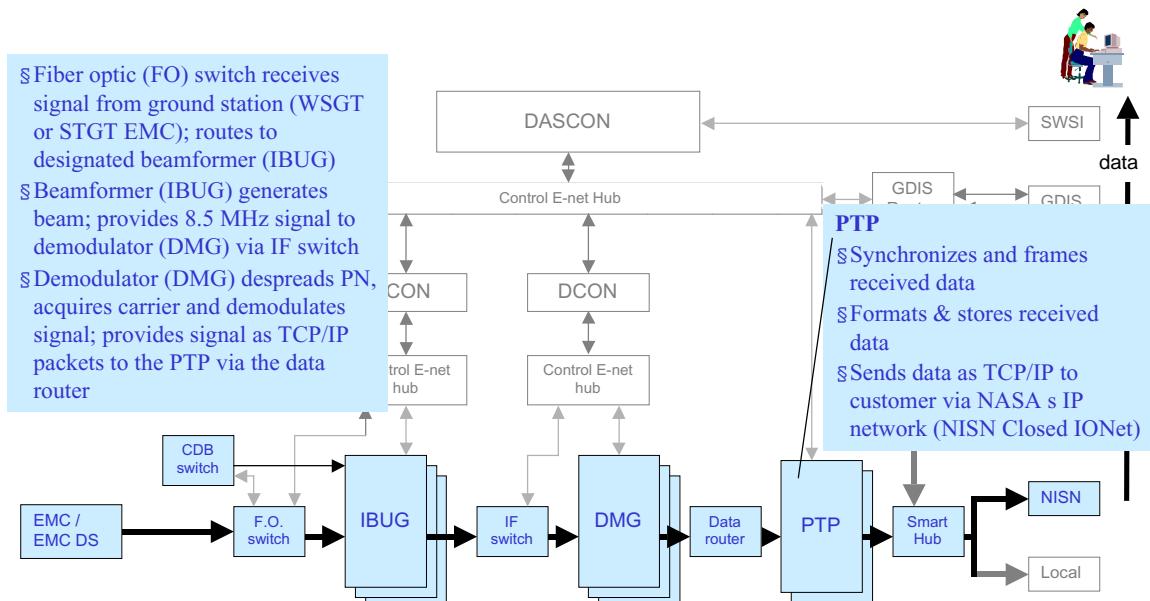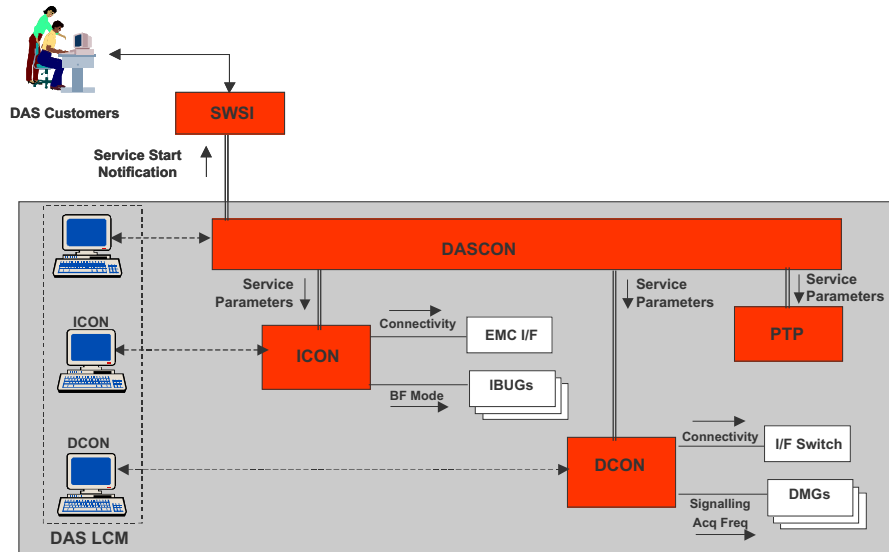
## 4.4   Service Activation & Service Control

Activating DAS services is an automatic function provided by DAS without interaction or intervention from operators or customers, as shown in Figure 4.  Prior to the start of a service, DASCON sends service configuration parameters to ICON and DCON.   ICON provides configuration commands to the beamformers and the ground station interface, while the DCON sends configuration commands to the IF switch and the demodulators.   DASCON sends configuration parameters directly to the data format/archive server, specifically, the PTP.

During service operations, ICON and DCON collect and forward status from subordinate elements to DASCON.  DASCON solicits status from the PTP.  DASCON monitors service and provides user performance data to the customer once per minute via SWSI.  DASCON also provides alerts.  Due to automation, no routine operator intervention is required to schedule, activate, or monitor DAS services.

## 4.5   Data Service: Real-Time and Archive

DAS provides real-time data to customers during service periods and archives data for future "playback" to customers, on request.  The data signal flow through DAS is illustrated in Figure 5.  The fiber optic (FO) switch receives the spacecraft signal from the ground station and routes the signal to the designated beamformer.  The beamformer (IBUG) generates the antenna beam and outputs a 8.5 MHz signal to the demodulator (DMG) via the IF switch.  The demodulator (DMG) despreads the PN, acquires the carrier,

8

**Figure 4: DAS Service Activation**



Fiber optic (FO) switch receives signal from ground station (WSGT or STGT EMC); routes to designated beamformer (IBUG)

Beamformer (IBUG) generates beam; provides 8.5 MHz signal to demodulator (DMG) via IF switch

Demodulator (DMG) despreads PN, acquires carrier and demodulates signal; provides signal as TCP/IP packets to the PTP via the data router

**PTP**

Synchronizes and frames received data

Formats & stores received data

Sends data as TCP/IP to customer via NASA s IP network (NISN Closed IONet)

**Figure 5: DAS Data Signal Flow**

and demodulates the signal. The demodulator then provides the data as TCP/IP packets to the PTP via the data router. Finally, the PTP synchronizes and formats the received data, and stores the data. The PTP sends the data as TCP/IP packets to the customer via NASA's IP network (NISN Closed IONet).

The customer signal is typically formatted as a stream of fixed length frames with an attached marker. The DAS PTPs are capable of recognizing and delimiting frames if the spacecraft telemetry conforms to CCSDS recommendations. DAS supports CCSDS telemetry formats such as Standard Formatted Data Unit (SFDU), NASA Internet Protocol Data Unit (IPDU), NASA Low Earth Orbit–Terminal (LEO-T), and others. Spacecraft telemetry not conforming to CCSDS recommendations and frame structure are encapsulated as a series of TCP/IP packets for transmission to the customer.

Real time data is routed to a customer-specified destination address consisting of a TCP port number and an IP address. DAS routes the customer data upon customer request (i.e., no FTP access by users) at a rate dependent on the bandwidth that NISN IOnet can support  Since DAS is connected to the NISN Closed IOnet, all out-going data is passed through the NISN  Secure Gateway for customers not on the Closed IOnet  Customers may establish a local interface to DAS at the WSC or GRGT locations using TCP/IP/Ethernet protocols.

DAS automatically records only processed telemetry as it is to be transmitted for delivery.  Storage capacity is allocated based on the customer service level agreement while storage duration is maintained based on each service request.  A minimum capacity of 100 Mbytes per customer is provided with a maximum duration of 30 days.  DAS customers can request playback of any stored service period with the data delivery the same as for real-timer services (i.e., a stream of formatted TCP/IP packets).

## 5   Conclusions and Future Development

The new NASA Space Network DAS System provides a low-data rate, low-cost return telemetry data service for spacecraft in earth orbit.  DAS provides both dedicated, continuous (24x7) links for receiving telemetry data and single-event "on-demand" data service.  This type of service enables missions to rapidly re-point instruments for observation of cosmic and earth-based events or for receiving alert messages.  DAS operations are automated requiring little interaction between customer mission operations centers and DAS.  DAS does not require operators for routine service.  The DAS architecture builds on common and specialized COTS equipment, such as beamformers and data formatting and archiving systems.

By using a modular architecture that can be easily expanded to a nearly limitless number of users and standard networking connections (TCP/IP) for data delivery to customer mission operations centers, DAS provides a building block for future space internetworking.  The key to broadening the role of DAS lies in the development of an automated forward link capability, a space segment networking (e.g., IP) protocol, and an intelligent routing capability that addresses the problem of distributing messages to orbiting spacecraft.  An automated forward link capability would add a capability that would allow both DAS Customers and autonomous spacecraft to send Internet messages to spacecraft.  This new capability presupposes the existence of a common space internetworking protocol allowing the bi-directional flow of information between customers and their spacecraft as well as between spacecraft.

## References

1       W. Holmes, Jr., "NASA's Tracking and Data Relay Satellite System," IEEE Communications Society Magazine, pp. 13-20, September 1978

2       D. Brandel, W. Watson, & A. Weinberg, "NASA's Advanced Tracking and Data Relay Satellite System for the Years 2000 and Beyond," Proceedings of the IEEE, p. 1141-1151, July 1990

3       D. Zillig, R. McOmber, & W. Horne, "Demand Access Service for TDRSS Users," AIAA 16th International Communications Satellite Systems Conf., Washington, DC, 25-29 Feb 1996

4       D. Zillig, R. McOmber, & N. Fox, " TDRSS Demand Access Service: Application Of Advanced Technology To Enhance User Operations," SpaceOps98, Tokyo, 1998

5       K. Hogie, E. Criscuolo, R. Parise, "Link and Routing Issues for Internet Protocols in Space," 2001 IEEE Aerospace Conference, Big Sky, MT, March 2001

6       P. Liebrecht, A. Kelly, R. Flaherty, M. Schoeberl, W. Horne, & D. Zavetz, "Satellite Internetworking & Messaging in Support of the Earth Science Constellation," Space Ops 2000, Toulouse France, June 2000

7       C. Kwadrat, W. Horne, & D. Zillig, "The NASA Space Network Demand Access System: A Building Block Toward the Space Internet," First Joint Space Internet Workshop, GSFC, Nov 2000